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## EDITORIAL

# IEEE ACCESS SPECIAL SECTION: CYBER-PHYSICAL SYSTEMS

In recent years, there is an increasing synergy between computational technologies and physical components. So-called Cyber-Physical Systems (CPS) are composed of a collection of devices interacting with each other and communicating with the physical world. They integrate computation and communication aspects together with control and monitoring techniques. Various CPS applications can be found in almost all areas of human life, such as manufacturing systems, smart grids, robotics, transportation systems, medical devices, military, home area networks and smart buildings.

The aim of the Special Section in the IEEE ACCESS on “Cyber-Physical Systems” is to discuss recent advances of the design, modeling, specification, analysis, verification and application merits of CPS. These involve interdisciplinary fields of science, and so a wide range of topics have been covered. The call for papers met with a very enthusiastic response with 70 submissions. After a rigorous review process, 23 articles were finally accepted.

In the article, “PsCPS: A distributed platform for Cloud and fog integrated smart cyber-physical systems,” by Al-Jaroodi and Mohamed, a distributed platform named PsCPS is proposed. Such a platform includes system and application agents in order to provide different services for cloud and fog integrated smart cyber-physical systems (sCPS). Contrary to the other approaches, PsCPS offers a generic agent-based platform that facilitates the development and deployment of different sCPS applications.

A self-governing false data injection attack method with exploitation and exploration mechanisms is analyzed in “Power system security under false data injection attacks with exploitation and exploration based on reinforcement learning,” by Wang *et al.* This attack is a potential threat to the security of smart grids, in which a malicious attacker injects false data into the control and communication system to disrupt its normal operation. The results presented in the article may help in recognizing vulnerabilities and enhancing security of power systems.

The article by Zhou *et al.* “Fog computing-based cyber-physical machine tool system,” deals with a new architecture of computer numerical control (CNC) machine tools. In particular, a fog computing-based cyber-physical machine tool system is proposed. This intelligent system serves as a bridge between cyber space and physical CNC machine tools.

A novel model of downlink cooperative multiple-input single-output wireless sensor networks is shown in the article “Performance analysis of DF/AF cooperative MISO wireless sensor networks with NOMA and SWIPT over Nakagami- $m$  fading,” by Tran *et al.* Three antenna-relay-destination selection solutions, i.e., sink node—high-priority (SHS), sink node—relay (SRS), and sink node—low-priority (SLS) were investigated and compared.

In the article by Darong *et al.* “Identification and prediction of urban traffic congestion via cyber-physical link optimization,” an algorithm oriented for the regulation of the traffic congestion is introduced. Since an urban road net consists of interconnected roads, it can be considered as a cyber-physical system, where the corresponding detected data of each road is obtained by sensors. The proposed method is able to perform the accurate prediction and evaluation of the traffic states in local urban areas.

The feasibility of social cooperation among prosumers in peer-to-peer (P2P) energy trading is explored in the article, “Peer-to-peer energy trading with sustainable user participation: a game theoretic approach,” by Tushar *et al.* The proposed energy trading technique is designed through a canonical coalition game (CCG). It is proven that the proposed scheme satisfies the consumer-centric property to ensure the sustainable participations of the P2P trading market.

A fuzzy join operation for big data lakes is shown in the article, “Fuzzy join for flexible combining big data lakes in cyber-physical systems,” by Małysiak-Mrozek *et al.* Such an operation transforms numerical values of joined data sets into fuzzy sets. Two variants of such join operation are considered. The first one refers to fuzzy numbers, while the second one deals with linguistic terms. The conducted experiments confirm that the proposed solution can be successfully applied in processing large volumes of data delivered by cyber-physical systems.

The article by Szyrka *et al.* “Discrete-time systems modeling and verification with alvis language and tools,” deals with the Alvis language. This formal modeling methodology is intended for developing concurrent systems, including real-time, embedded, and distributed systems. The formal definition and semantic of timed models are shown and discussed. Furthermore, an algorithm for state space generation is presented. In particular, a labeled transition system

(LTS) as a universal method of state space representation is applied.

A new orthogonal firefly algorithm (OFA) is proposed in the article, “Collision-free fuzzy formation control of swarm robotic cyber-physical systems using a robust orthogonal firefly algorithm,” by Xu and Huang. The idea is based on the fusion of the robust Taguchi method and ranking mutation. The presented collision-free fuzzy formation control strategy of swarm robotic cyber-physical systems has been realized by using field programmable gate arrays (FPGAs).

The predictive control for mission planning framework is considered in the article, “When time matters: predictive mission planning in cyber-physical scenarios,” by Gaggero *et al.* In particular, predictive control is applied in the selection of the best time instants to change the assignments of tasks. The proposed predictive mission planning (PMP) optimizes performances and prevents from too many changes of tasks.

Analysis of cyber-physical systems is the main purpose of the article by Wisniewski *et al.* “C-Exact hypergraphs in concurrency and sequentiality analyses of cyber-physical systems specified by safe Petri Nets.” In particular, hypergraph theory is applied to obtain the concurrency and sequentiality relations in the primary specification of a cyber-physical system, i.e., in a safe Petri net. It is shown that, under certain assumptions, the solution (concurrency or sequentiality relations) can be computed with polynomial delay. The presented methods are supported formally, by adequate theorems and proofs. The computational complexity of the proposed algorithms is analyzed and estimated. Finally, results of experimental research are discussed and analyzed.

The article entitled “A technology mapping of FSMs based on a graph of excitations and outputs,” by Kubica, *et al.* proposes a logic synthesis method for finite-state machines (FSMs) oriented on the implementation in the complex programmable logic devices [12]. The proposed algorithm is aimed at the minimization of the resources of a device. Thus, it leads to the reduction of the cost of a destination cyber-physical system. The presented approach is based on a graph of excitations and outputs, which is introduced in the article.

“Safety risk monitoring of cyber-physical power systems based on ensemble learning algorithm,” by Li *et al.* is an analysis of the cyber-physical power systems (CPPS). In particular, a novel method for CPPS log analysis is proposed. Furthermore, an Ensemble Prediction Algorithm Based on Time series is introduced to predict abnormal features during network traffic analysis. Additionally, safety risk monitoring of CPPS is considered in the article.

In “Leveraging the capabilities of industry 4.0 for improving energy efficiency in smart factories,” Mohamed, *et al.* deal with the opportunities and roles of Industry 4.0 in reducing energy consumption in smart factories. The influence of Industry 4.0 on energy improvements in smart factories is investigated and analyzed. Additionally, an enabling architecture and its components are discussed. The presented architecture consists of CPS manufacturing services layer, fog manufacturing services layer, cloud manufactur-

ing services layer, and blockchain-based service-oriented middleware.

The logic synthesis techniques oriented on the implementation of a system in FPGA are presented in the article, “Methods of improving time efficiency of decomposition dedicated at FPGA structures and using BDD in the process of cyber-physical synthesis,” by Opara *et al.* The main idea is based on the decomposition of multi-output functions. The algorithms shown in the article are universal and can be applied for a wide range of FPGA families.

An application of a live and safe Petri net to specify the control part of a direct matrix converter with space vector modulation (SVM) and transistor commutation is shown in the article entitled, “Petri Net-based specification of cyber-physical systems oriented to control direct matrix converters with space vector modulation,” by Wisniewski *et al.* The proposed technique aims for further implementation in a programmable device (in particular, an FPGA device is used). Contrary to traditional solutions, the presented design methodology does not involve external tools, nor additional conversions. Additionally, it highly utilizes the concurrency properties of FPGAs.

The concept of a wirelessly powered CPS is presented in the article, “Implementation of a battery-free wireless sensor for cyber-physical systems dedicated to structural health monitoring applications,” by Loubet, *et al.* An original battery-free implementation of a wireless sensing node (SN) for structural health monitoring is shown. Such an SN operates as a part of a cyber-physical system and it is wirelessly powered by a wireless power transmission.

The article by Bhattacharjya, *et al.* “A lightweight and efficient secure hybrid RSA (SHRSA) messaging scheme with four-layered authentication stack,” deals with security aspects of cyber-physical systems. To improve the traditional Rivest-Shamir-Adleman (RSA) algorithm, a secure hybrid RSA messaging scheme is shown. The idea applies a four-layered authentication stack (Diffie-Hellman Key exchange, 3-way Handshaking, Peer to Peer Authentication by Diffie-Hellman Key exchange, PFS grade 4 – Older Diffie-Hellman without curves). The performance of the presented solution is experimentally verified and compared with the traditional RSA algorithm.

An enhancement resilience for a multi-agent framework for complex CPS is proposed in “A distributed multi-agent framework for resilience enhancement in cyber-physical systems,” by Januário *et al.* The idea relies on the diversity of distributed physical devices in the context of heterogeneous communication networks. The proposed resilient architecture is described and analyzed in details. Additionally, the results of experimental research are presented and discussed.

A novel method of model predictive control is shown in “A probabilistic algorithm for predictive control with full-complexity models in non-residential buildings,” by Gómez-Romero *et al.* In particular, the manuscript focuses on the reduction of energy consumption in non-residential buildings. The developed control system is implemented and tested in a

real building (an office in Helsinki). Performed simulations of the proposed technique indicate energy savings from 20% to 35%, depending on the season of a year.

Two modeling and simulation (M&S) issues for defense cyber-physical systems are discussed in the article “Model-based design of defense cyber-physical systems to analyze mission effectiveness and network performance,” by Kang *et al.* The first one applies model-driven development, while the second one is based on the simulation analysis. The computational and physical capabilities of CPS are analyzed in details.

The concept and practical realization of a cyber-physical power system is presented in the article by Leżyński, *et al.* “Design and implementation of a fully controllable cyber-physical system for testing energy storage systems.” In particular, implementation and analysis of ancillary system services provided with the application of energy storage are considered. The presented solution is fully controllable, enabling the flexible realization of control algorithms developed for all of the components (power source, loads, and energy storage).

Finally, the invited article, “On enabling technologies for the internet of important things,” by Lohstroh *et al.* deals with the safety-critical cyber-physical systems. Safety, reliability, privacy, and security in so-called Internet of Important Things (IoIT) are studied and analyzed and timing aspects are discussed. In particular, coordination mechanisms and synchronization techniques are analyzed in details. Programming models are also presented. Finally, the article concludes with the divagations related to the logical and physical time in cyber-physical systems.

In conclusion, we would like to thank all the authors who submitted their research articles to our Special Section. We highly appreciate the contributions of the reviewers for their constructive comments and suggestions. We would also like to acknowledge the guidance from the Editor-in-Chief and staff members. We would like to especially thank Mrs. Margery Meyer for her invaluable support and helpful suggestions during the whole management process of this Special Section.

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